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# Small-Size Tapered Slot Antenna (TSA) Array for 5G Cellular Communications

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**Abstract** — Design and development of a compact tapered slot antenna (TSA) array for the fifth generation (5G) cellular communications is described in this study. The proposed low-profile TSA element is designed on a Rogers RT 5880 ( $\epsilon=2.2$  and  $\delta=0.0009$ ) dielectric to work in the frequency range of 21 to 23 GHz. The configuration of the employed TSA antenna elements is composed of a slot-line flare from a small gap to a large opening, matching to free space's wave. The TSA elements are fed by hockey-stick baluns. Eight elements of TSAs with well-defined end-fire radiation patterns have been used on the top portion of mobile-phone PCB to form a  $1 \times 8$  linear phased array design. In addition, the performance of the antenna in the vicinity of user's hand has been investigated in this study. The results show that the proposed design provides good characteristics in terms of S-parameters, antenna gain, efficiency, and beam steering, which is fitting the need of 5G cellular communications.

In addition, using eight rows of the designed 22 GHz TSA array, radiation performance of  $8 \times 8$  planar phased array has been studied. More than 20 dB realized gain, and -0.5 dB (90%) total efficiency have been obtained when its beam is tilted to  $0^\circ$  elevation. The results show this TSA antenna arrays satisfy general requirements for use in 5G platforms.

**Index Terms** — 5G wireless networks, cellular communications, planar phased array, TSA.

## I. INTRODUCTION

Compared with the current and previous generations (1G to 4G) of wireless communications, fifth generation (5G) networks are proposing to use the higher frequency bandwidths due to growing need for wider bandwidths and higher data rates [1-2]. Compared with the carrier frequencies used today (1G-4G < 4 GHz), 5G mobile networks will use broader mm-Wave frequency bandwidths [3]. 22, 28, and 38 GHz are some of the candidate bands for 5G wireless communications [4]. Our work represents a primarily

study on the design of 22 GHz phased array tapered slot antenna for the future 5G cellular communication applications.

Tapered slot antenna (TSA) has received considerable amount of research effort owing to their attractive futures such as high gain and relatively wide bandwidth compared with the typical designs such as patch antennas. They can provide excellent directional propagation at the higher frequencies and could be used for radar, detecting and phased array applications [5-6]. The TSA array with compact size and high-gain characteristics is also among one of the most promising candidate satisfying all requirements of 5G systems which could be used to form multiple antenna systems for 5G systems [7].

The designed TSA is operating from 21 to 23 GHz and has compact-size, sufficient-gain, high-efficiency, and good beam-steering property. Eight elements of the TSAs formed a linear phased array in the edge region (top-side) of a mobile phone PCB. Another set of the linear phased array could be used on the bottom portion of the PCB. Furthermore, 64-elements of the antennas have been used to form a planar phased array with high-gain property. The designed antenna has a good potential to be used in linear and planar phased array applications.

## II. SINGLE ELEMENT TSA

The configuration of the single element TSA is shown in Fig. 1. As illustrated, it contains a slot-line flare from a small gap to a large opening, matching to free space's wave with hockey-stick balun feed technique. The antenna has a compact size of  $W_S \times L_S$ . The design parameters of the antenna and the proposed array are specified in Table I.

The simulated  $S_{11}$  characteristic of the designed TSA is illustrated in Fig. 2. It can be seen that the proposed TSA antenna covers the frequency band from 21 to 23 GHz (2 GHz bandwidth for  $S_{11} < -10$ ) and has a reflection coefficient of -30 dB at the resonance frequency (22 GHz).

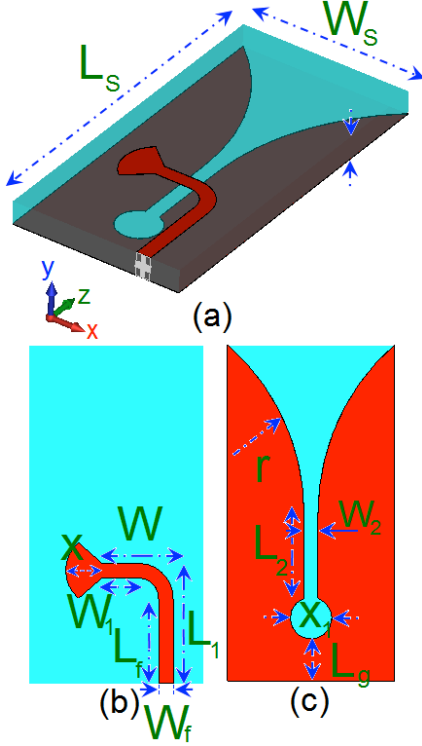


Fig. 1. Proposed TSA configuration, (a) side view, (b) top layer, and (c) bottom layer.

Table I: Dimensions of the Antenna Parameters

Parameter	$W_X$	$L_X$	$W_S$	$L_S=L_a$	$W_a$	$h$
Value (mm)	48	42.8	6	12	48	0.8
Parameter	$L_g$	$W$	$L$	$W_1$	$L_1$	$r$
Value (mm)	1.5	2.25	4	1.1	4.25	8
Parameter	$W_2$	$L_2$	$W_f$	$L_f$	$X$	$X_1$
Value (mm)	0.5	3	0.5	3	1.25	1.5

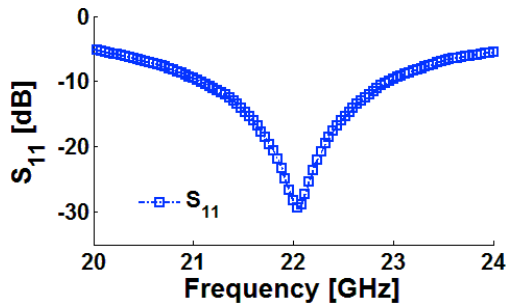


Fig. 2.  $S_{11}$  characteristic of the LTSA.

The frequency response ( $S_{11}$ ) of the designed TSA can be controlled by changing the values of critical parameters such as the width of the hockey-stick balun. Figure 4 depicts the  $S_{11}$  characteristics of the antenna for different values of  $W_1$ . As illustrated, when the value of  $W_1$  increases from 2.05 to 2.45 mm, the resonance of the antenna response increases from 22.05 to 22.6 GHz.

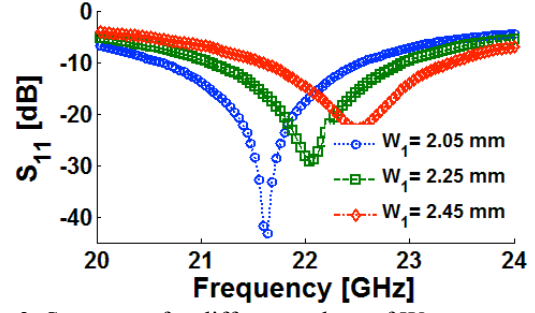


Fig. 3.  $S_{11}$  curves for different values of  $W_1$ .

The 3D and radiation pattern of the antenna at 22 GHz is illustrated in Fig. 4 (a). As can be seen, the antenna has desirable end-fire radiation property with 4.45 dB realized gain (IEEE gain  $\times$  mismatch). In addition, the efficiency characteristics of the antenna over the operation band is described in Fig. 4 (b). Based on the obtained results, the antenna has high efficiency function at the different frequency of the operation band (especially at the resonance frequency=22 GHz).

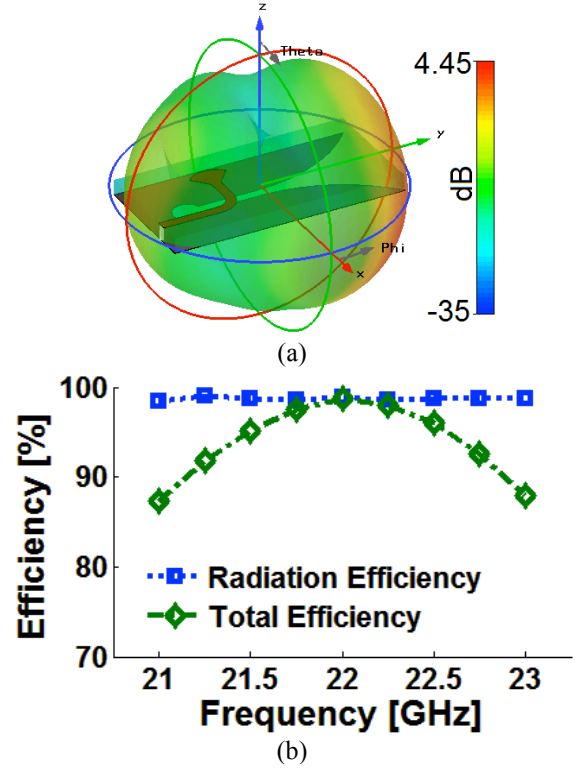


Fig. 4. (a) Radiation pattern and (b) efficiency characteristics of the TSA.

### III. THE PROPOSED TSA LINEAR ARRAY

The proposed phased array antenna is designed using eight elements of TSAs. Figure 5 illustrates the configuration of the linear phased array. The array has a compact size of  $W_a \times L_a = 48 \times 12$  mm<sup>2</sup>. The antenna element are arranged with a distance of  $d = W_s$ .

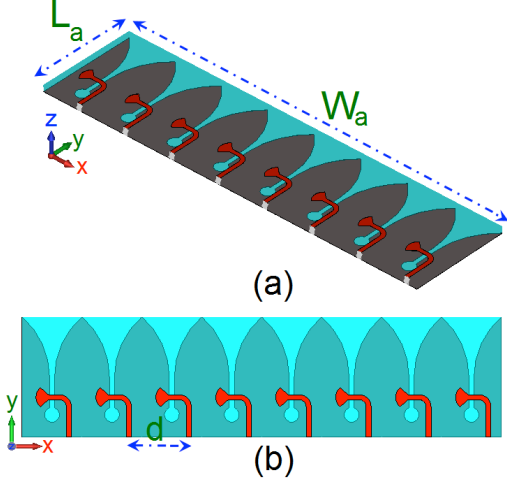


Fig. 5. Geometry of the linear array, (a) side view, and (b) top view

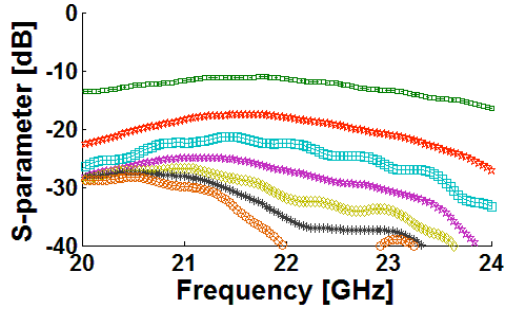


Fig. 6. S parameters of the array shown in Fig. 5.

Figure 6 shows the S parameters ( $S_{21}$  to  $S_{81}$ ) of the array. As shown, the array has a good performance in the frequency range of 21 to 23 GHz. The highest mutual-coupling characteristic ( $S_{21}$ ) between the TSA elements is less than -11 dB at the center frequency of the operation band (22 GHz).

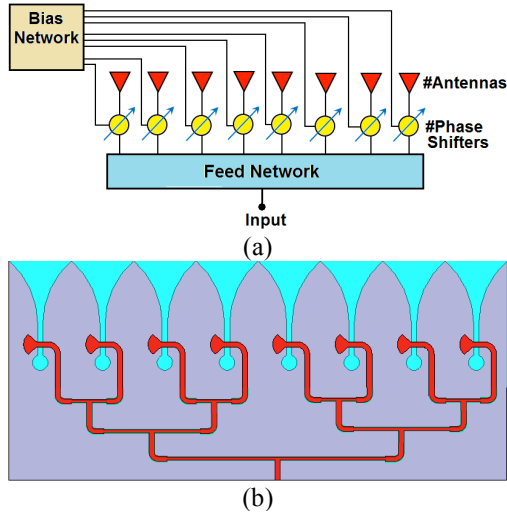


Fig. 7. (a) Phased array architecture for the proposed design and (b) typical 1:8 feed network.

Figure 7 (a) illustrates a system architecture in which the proposed linear phased array antenna can be used for 5G applications. For operations using time division duplex, the feed network can be implemented using low loss phase shifters (such as HMC933LP4E [8]) for beam steering).

One of the important issue to achieve a functional array antenna is the feed network. In the proposed design, a  $1 \times 8$  uniform linear array antennas could be used and each radiating element with equal magnitude must be excited. There are various techniques of feed network design for this purpose: parallel (Fig. 7 (b)), series, and etc. The power dividers (such as Wilkinson) divide the power to equally  $1:N$  and also unequally by changing the input and output [9].

#### IV. APPLICATION OF THE PROPOSED ARRAY FOR 5G HANDHELD DEVICES

Figure 8 depicts the configuration of the 5G mobile-phone antenna. It consists of eight 22-GHz TSA elements used to form a linear phased array in the edge region (top-side) on a mobile phone PCB. Another set of the designed array could be used in two sets of phased arrays in the top and bottom portion of the mobile phone PCB [10].

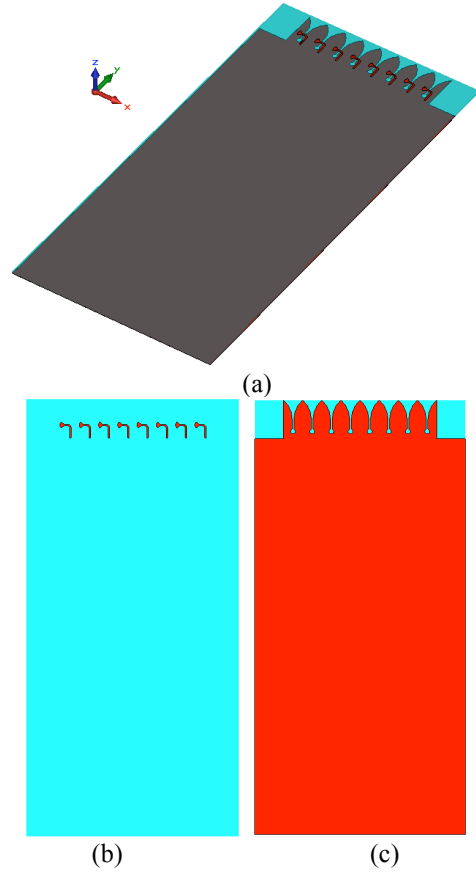


Fig. 8. Phased array 5G antenna configuration, (a) side view, (b) top layer, and (c) bottom layer (GND).

The simulated S-parameters ( $S_{11}$  to  $S_{81}$ ) of the designed 5G mobile-phone antenna are shown in Fig. 10. The antenna operates at the central frequency of 22 GHz (2 GHz bandwidth). It can be seen that the highest mutual-coupling characteristic between the elements is less than -11 dB which is sufficient for phased array applications.

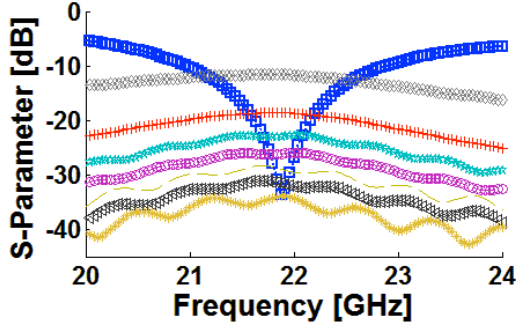


Fig. 9. Simulated S-parameters of the proposed 5G mobile-phone antenna.

The beam steering characteristic of the antenna with directivity values at different scanning angles ( $0^\circ$  to  $75^\circ$ ) are shown in Fig. 10. As seen, the proposed antenna has a sufficient beam-steering function in the scanning range of 0 to 75 degree. It should be noted that for plus-minus ( $\pm$ ) scanning angles, the beam-steering characteristic of the antenna are almost the same.

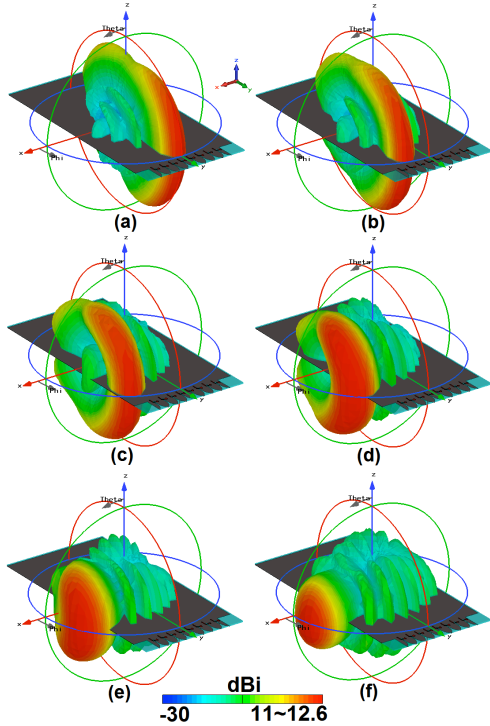


Fig. 10. 3D Radiation beams with directivity values at, (a)  $0^\circ$ , (b)  $15^\circ$ , (c)  $30^\circ$ , (d)  $45^\circ$ , (e)  $60^\circ$ , and (f)  $75^\circ$ .

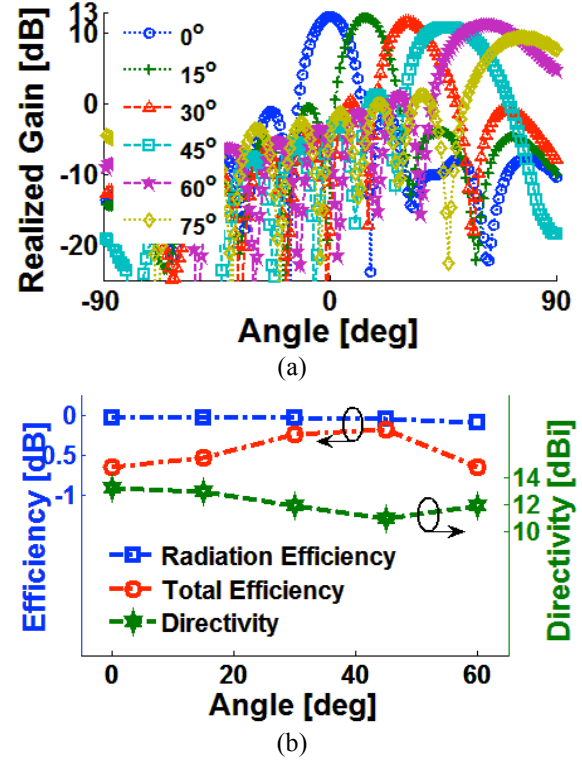


Fig. 11. (a) Realized gains and (b) radiation properties of the antenna at different scanning angles.

Figure 11 (a) illustrates the simulated realized gains of the proposed 5G mobile-phone antenna at different angles. From the beam steering characteristics shown in Fig. 11, it can be observed that the antenna has sufficient gains at different scanning angles. For the scanning range of 0 to 75 degree, the antenna gains are almost constant and more than 10 dB.

Figure 11 (b) describes the fundamental radiation properties of the antenna beams for the scanning range of 0 to 70. As seen, in the scanning angle of 0-60 degree, the antenna has more than -0.1 dB -0.5 dB radiation and total efficiencies, respectively. It is noted that the antenna has high efficiencies for different scanning angles. Furthermore, when the scanning angle of the radiation beam is  $\leq +60^\circ$ , the proposed antenna has more than 11 dBi directivity.

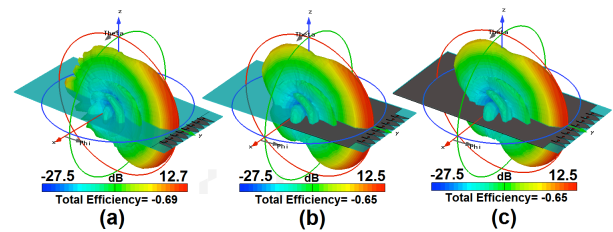


Fig. 12. Radiation characteristics of the 5G mobile-phone antenna (at  $0^\circ$ ) for different length of the ground plane, (a) full, (b) half, and (c) without PCB-GND.

The radiation performances of the proposed 5G mobile-phone antenna with different lengths of the PCB ground-plane have been investigated in Fig. 12. As illustrated, the size of PCB ground plane doesn't have significant impact on the radiation properties of the antenna in terms of gain and total efficiency.

The handsets for mobile communication systems are practically operated in the vicinity of a human body. Especially, the user's hand is one of the parts that touch the mobile handsets most frequently [11-12]. In general, the user's hand has a negative impact on the antenna performance in terms of efficiency, gain, impedance-matching and etc. Changing its position can increase/decrease the amount of the losses. The impact of user-hand on the performance of the proposed phased array TSA has been studied in this section.

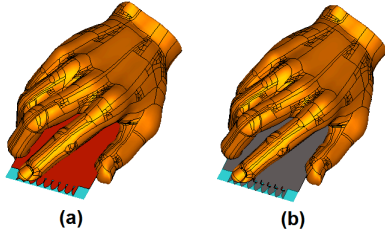


Fig. 13. Different placement of the antenna in the vicinity of user's hand, (a) bottom and (b) top positions.

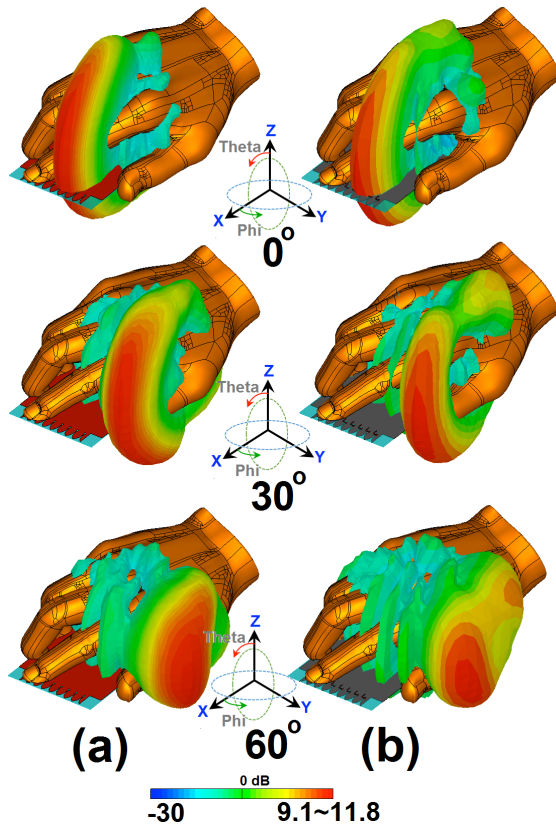


Fig. 14. Radiation beams at different scanning angles for, (a) bottom position, and (b) top position.

Figure 14 shows the 3D radiation beams of the antenna radiation patterns in the vicinity of user's hand for different scanning angles at different positions. As illustrated, the antenna has a good beam steering function with acceptable realized gain levels at different scanning angles. Table 2 summarizes the effect of user's hand on the properties of the proposed phased array Vivaldi antenna. The total losses of antenna parameters in terms of realized gain, radiation efficiency, and total efficiency are about 3 dB, 15%, and 25%, respectively.

Table 2: Total Losses of the Antenna Parameters

Antenna Parameters	Position (a)	Position (b)
Radiation Efficiency	10~25%	10~20%
Total Efficiency	20~35%	15~35%
Realized Gain	0.5~2.5 dB	1~2 dB

## VI. PLANAR PHASED ARRAY TSA ANTENNA

Figure 15 displays the 3D view of the planar phased array TSA. It can be observed, 64-elements of 22 GHz TSAs with hockey-stick balun Feeds have been used to form the proposed planar array design. The antenna has a compact size of  $W_x \times L_x$ .

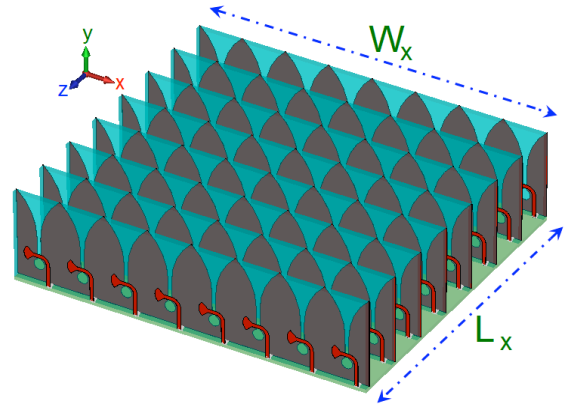


Fig. 15. 3D view of the planar phased array TSA.

The proposed planar phased array antenna is operating in the same operation band of the single element TSA (frequency range from 21 to 23 GHz). It has compact-size, high-gain, sufficient-efficiency and beam-steering properties. The designed planar array could be used for 5G base station or channel measurement applications.

The 3D directional radiation beams of the proposed antenna with directivity values at different angles are shown in Fig. 16. It can be seen that the antenna has a good beam steering characteristic with high-level realized gains. The planar phased array design has more than 21 dB realized gain when its beam is tilted to 0 degree.



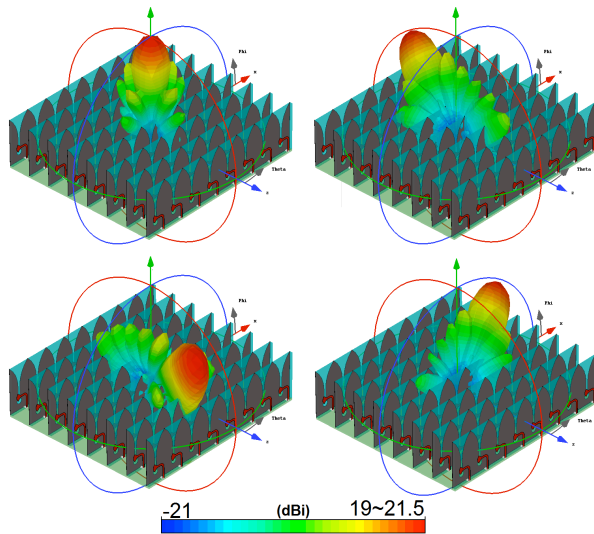


Fig. 16. 3D beams of the proposed phased array at different angles.

## V. CONCLUSION

A low-profile tapered slot antenna array for 5G channel measurement applications has been presented in this manuscript. The antenna is designed to work at 22 GHz which is one of the candidate bands for the future communications and has 2 GHz bandwidth. The array antenna has compact-size, high-gain/high-efficiency with good and beam-steering characteristic. Eight TSA elements formed a linear phased array in the top portion of the mobile-phone PCB. For the designed 5G mobile-phone antenna, fundamental radiation properties and also user's hand impact are studied. In addition, using  $8 \times 8$  elements of the single element 22 GHz TSA, a planar phased array with high-gain property is designed and its characteristics are investigated. Based on the obtained result, the antenna, its linear and planar arrays are effective for the requirement of 5G applications.

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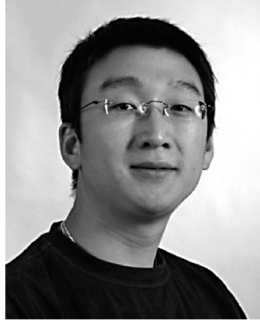
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mobile terminals with single antennas and he was chairing the various COST groups (swg2.2 of COST 259, 273, 2100 and now ICT1004) with liaison to 3GPP for over-the air test of MIMO terminals.



**Gert Frølund Pedersen** received the B.Sc. E. E. degree, with honor, in electrical engineering from College of Technology in Dublin, Ireland in 1991, and the M.Sc. E. E. degree and Ph. D. from Aalborg University in 1993 and 2003. He has been with Aalborg University since 1993 where he is a full professor heading

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